US007740810B2

(12) **United States Patent**
Hay et al.

(10) **Patent No.: US 7,740,810 B2**
(45) **Date of Patent: Jun. 22, 2010**

(54) **PHOTOCATALYST PROTECTION**

(75) Inventors: **Stephen O Hay**, South Windsor, CT (US); **Susan D. Brandes**, South Windsor, CT (US); **Norberto O. Lemcoff**, Simsbury, CT (US); **Timothy N. Obee**, South Windsor, CT (US); **Wayde R. Schmidt**, Pomfret Center, CT (US)

(73) Assignee: **Carrier Corporation**, Syracuse, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1524 days.

(21) Appl. No.: **11/011,730**

(22) Filed: **Dec. 14, 2004**

(65) **Prior Publication Data**

US 2006/0127288 A1 Jun. 15, 2006

(51) **Int. Cl.**
B01J 19/08 (2006.01)

(52) **U.S. Cl.** **422/186.04**; 422/186.3; 422/121

(58) **Field of Classification Search** 422/186.04, 422/186.3, 121; 96/96
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,990,311	A	2/1991	Hirai	
5,933,702	A	8/1999	Goswami	
5,993,738	A	11/1999	Goswani	
6,149,717	A	11/2000	Satyapal	
6,238,629	B1	5/2001	Barankova	
6,358,374	B1 *	3/2002	Obee et al.	204/157.3
6,508,982	B1	1/2003	Shoji	
6,607,702	B1 *	8/2003	Kang et al.	422/186.3

(Continued)

FOREIGN PATENT DOCUMENTS

CA	2192048	1/2004

(Continued)

OTHER PUBLICATIONS

Publication: "Chemical Vapor Deposition of Silicon Dioxide by Direct-Current Corona Discharges in Dry Air Containing Octamethylcyclotetrasiloxane Vapor: Measurement of the Deposition Rate" by Junhong Chen and Jane H. Davidson Jan. 10, 2003; Aug. 8, 2003.

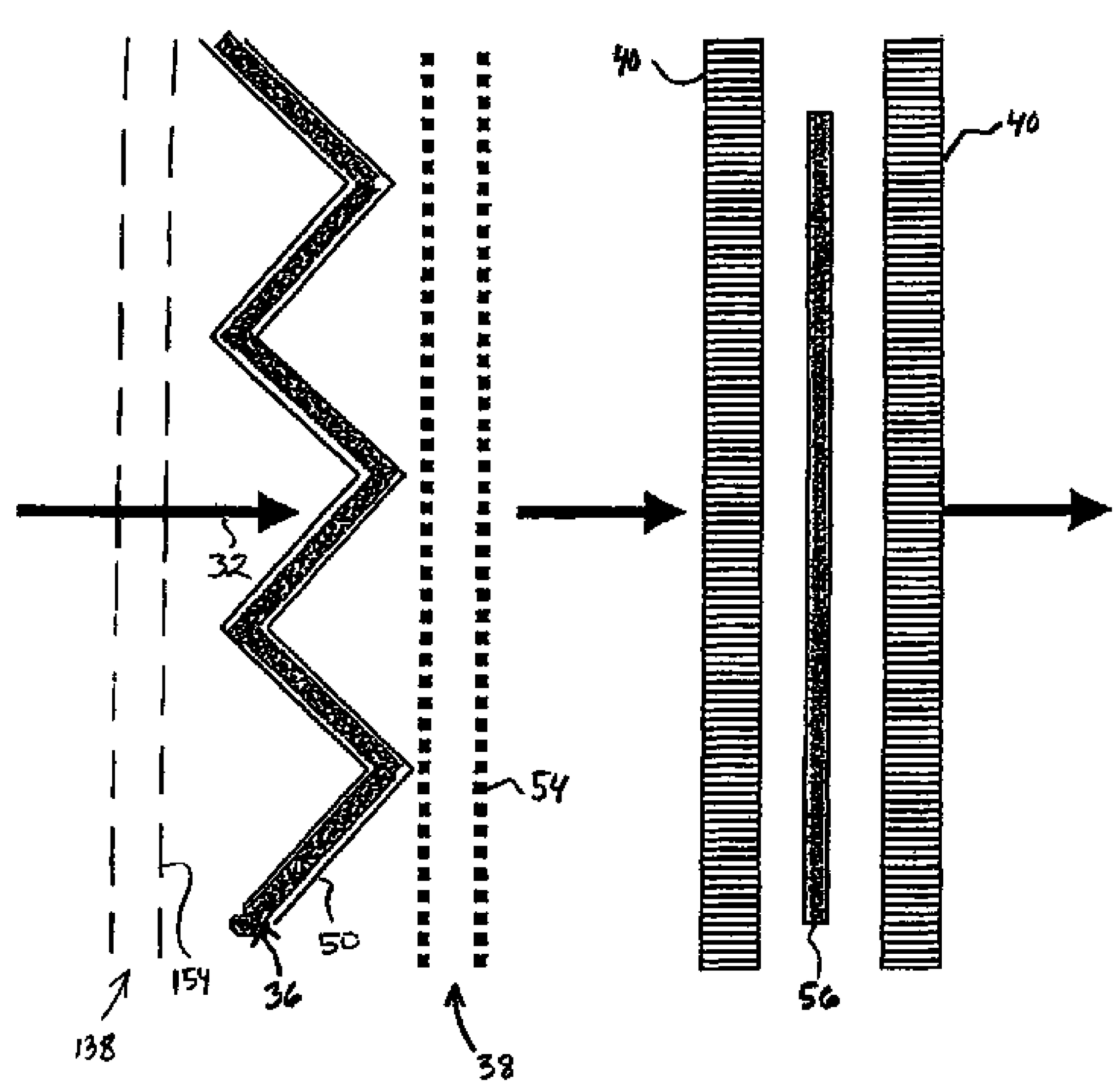
(Continued)

Primary Examiner—Kishor Mayekar
(74) *Attorney, Agent, or Firm*—Carlson, Gaskey & Olds PC

(57) **ABSTRACT**

An air treatment system includes a filter and heating element, a plasma device, and a photocatalyst and UV light that cooperate to purify an air stream flowing through the air treatment system and protect the photocatalyst from passivating effects of certain contaminants. The air treatment system operates in two different modes. In the first mode, the air treatment system primarily draws air from and returns air to a space, and the heating element and plasma device are selectively shut off. In the second mode, the air treatment system regenerates the filter using the heating element to selectively heat the filter and release adsorbed contaminants. The plasma device is selectively turned on and chemically transforms the released contaminants into solid contaminant products. The solid contaminant products are deposited on a biased electrode of the plasma device. The UV light is turned off to ensure that the photocatalyst is inoperable during the release and transformation of the contaminants. Once deposited, the essentially immobile and inert solid contaminant products are unlikely to damage the photocatalyst.

14 Claims, 4 Drawing Sheets



U.S. PATENT DOCUMENTS

6,680,033	B2	1/2004	Ishii	
6,866,828	B2 *	3/2005	Segawa et al.	422/186.04
6,955,708	B1 *	10/2005	Julos et al.	95/59
7,063,733	B2 *	6/2006	Mori et al.	96/135
2003/0089237	A1	5/2003	Jagtoyen et al.	
2004/0007000	A1	1/2004	Takeda et al.	
2004/0065078	A1	4/2004	Schafer-Sindlinger et al.	
2004/0175318	A1	9/2004	Segawa et al.	

FOREIGN PATENT DOCUMENTS

CN	2655913	11/2004
DE	10211810	10/2003
EP	1014006	6/2000
EP	1348448	10/2003
EP	1405663	4/2004
EP	1671659	6/2006
JP	2000102596	4/2000
WO	2005037335	4/2005

OTHER PUBLICATIONS

European Search Report mailed Feb. 29, 2009.
Search Report and written opinion mailed Nov. 27, 2008.
China Patent Office Action Dated Feb. 20, 2009.
International Search Report and Written Opinion Dated Mar. 5, 2007.

* cited by examiner

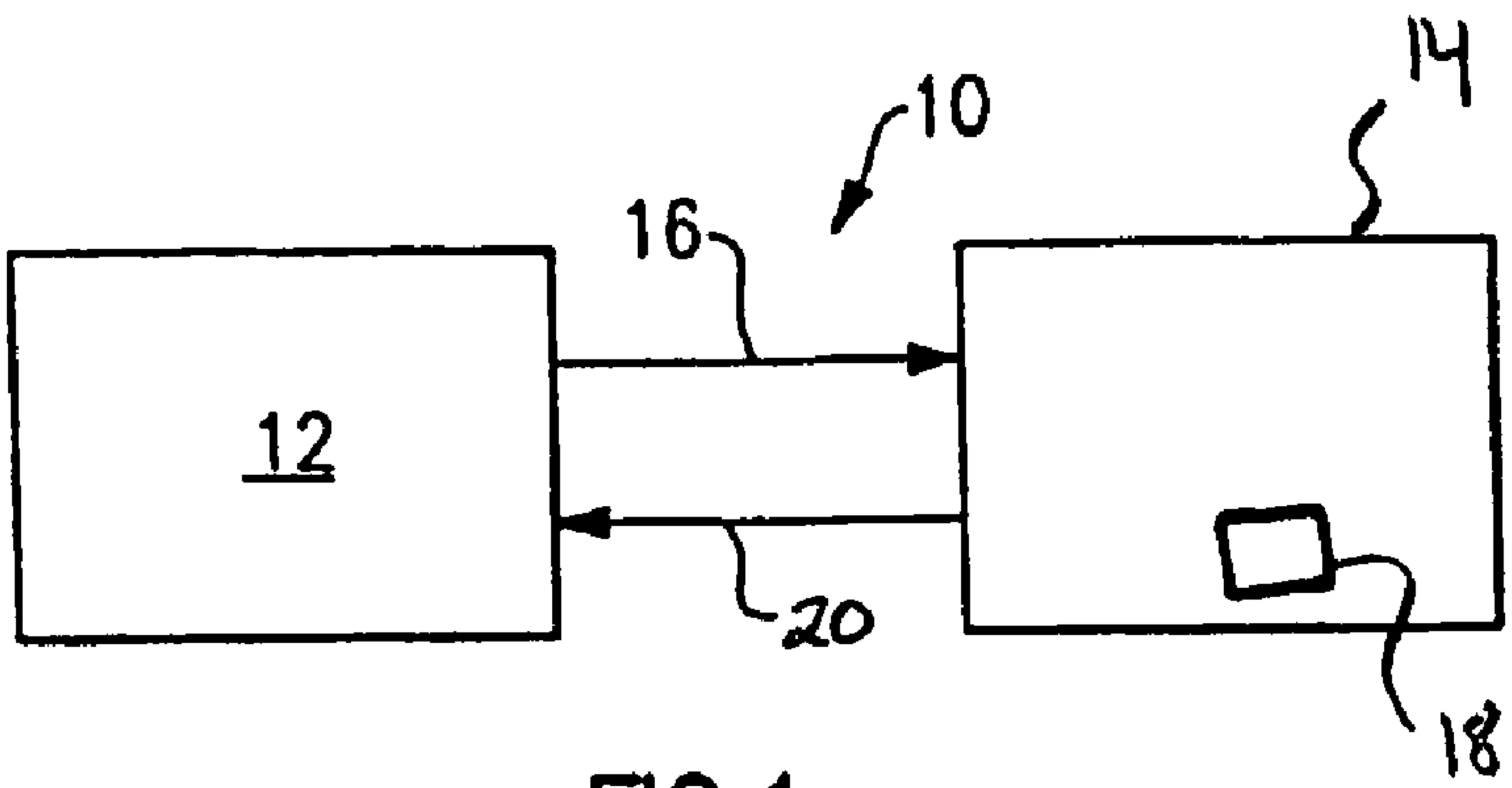


FIG.1

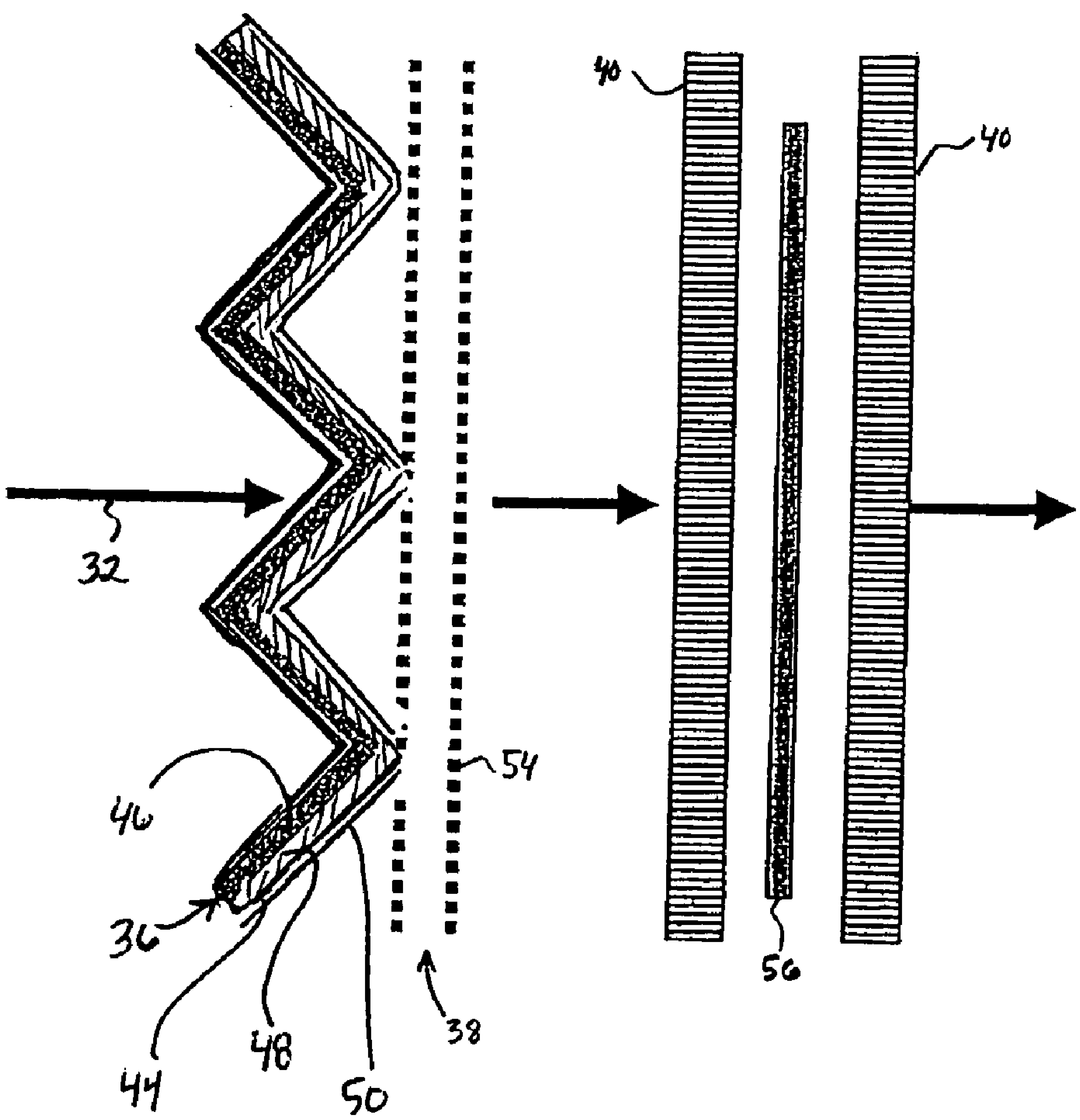


Fig. 4

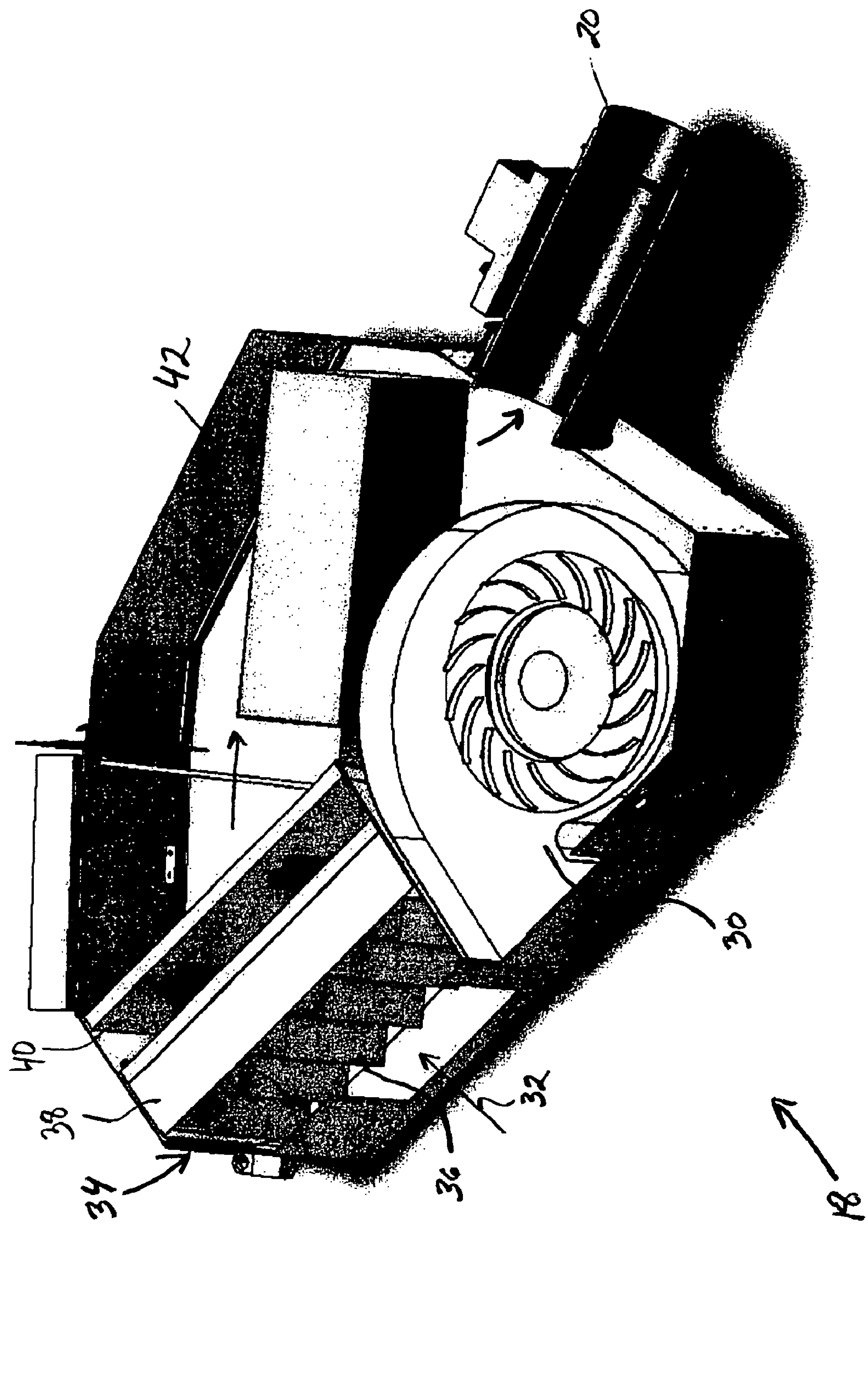


Fig. 2

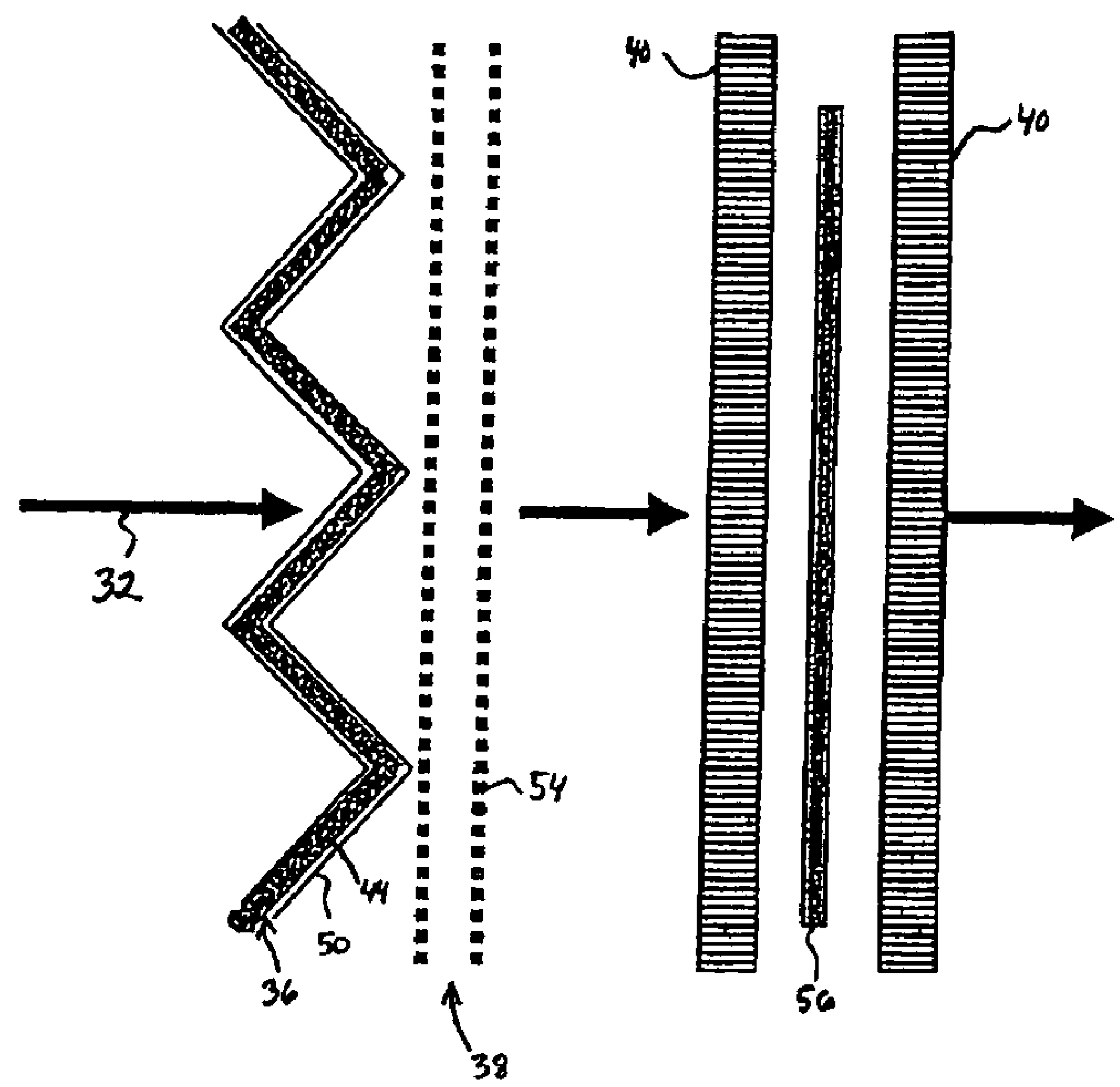


Fig. 3

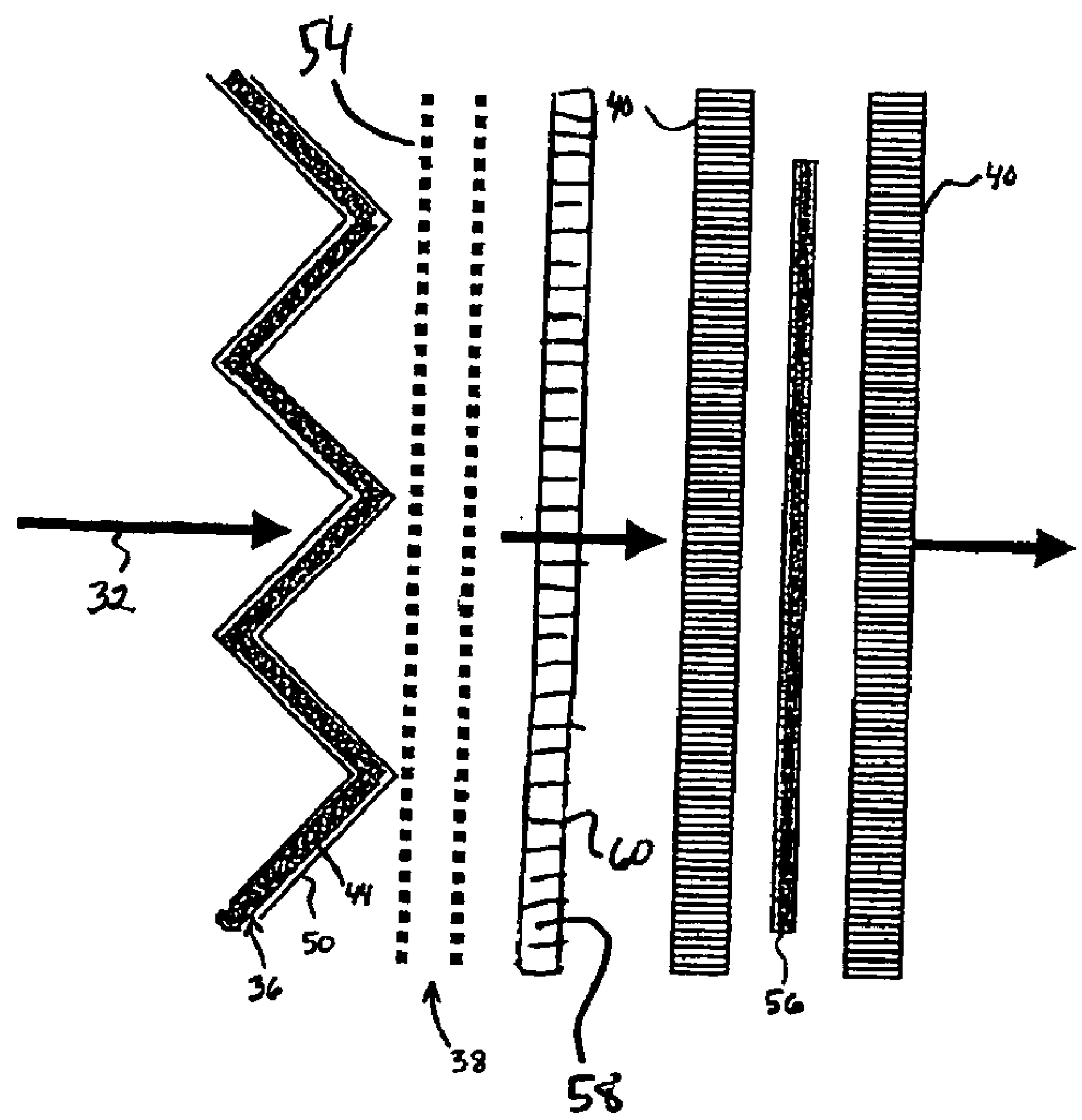


Fig. 5

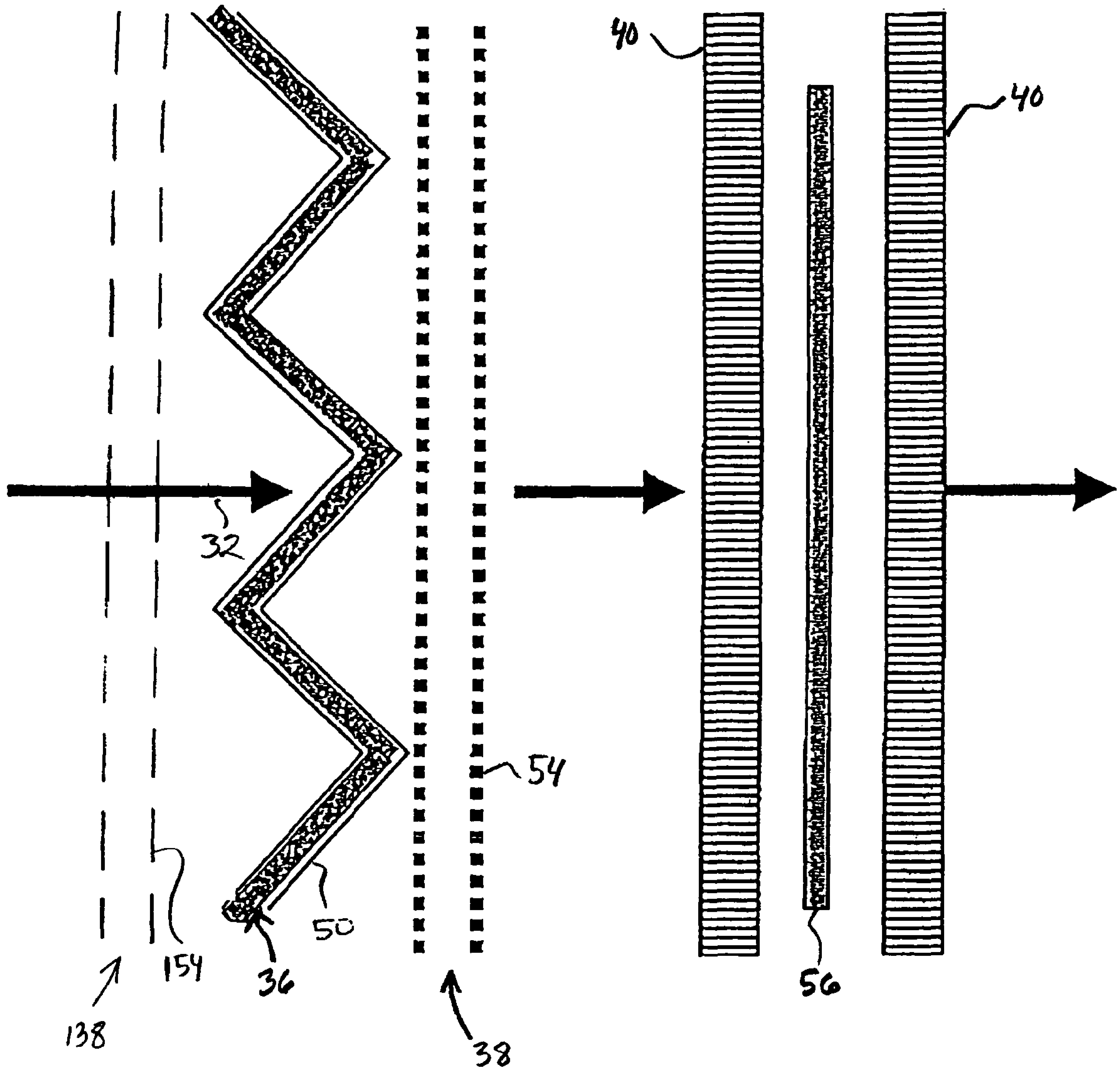


Fig. 6

PHOTOCATALYST PROTECTION

BACKGROUND OF THE INVENTION

This invention relates to air treatment modules and, more particularly, to protecting a photocatalyst in the air treatment module using a corona discharge device to remove contaminants from the air handling air stream.

Air treatment modules are commonly used in automotive, commercial and residential heating, ventilating, and air conditioning (HVAC) systems to move and purify air. Typically, an air stream flowing through the air treatment module includes trace amounts of contaminants such as biospecies, dust, particles, odors, carbon monoxide, ozone, semi-volatile organic compounds (SVOCs), volatile organic compounds (VOCs) such as formaldehyde, acetaldehyde, toluene, propanol, butene, and silicon-containing VOCs.

Typically, a filter and a photocatalyst are used to purify the air stream by removing and/or destroying the contaminants. A typical filter includes a filter media that physically separates contaminants from the air stream. A typical photocatalyst includes a titanium dioxide coated monolith, such as a honeycomb, and an ultraviolet light source. The titanium dioxide operates as a photocatalyst to destroy contaminants when illuminated by ultraviolet light. Photons of the ultraviolet light are absorbed by the titanium dioxide, promoting an electron from the valence band to the conduction band, thus producing a hole in the valence band and adding an electron in the conduction band. The promoted electron reacts with oxygen, and the hole remaining in the valence band reacts with water, forming reactive hydroxyl radicals. When contaminants in the air stream flow through the honeycomb and are adsorbed onto the titanium dioxide coating, the hydroxyl radicals attack and oxidize the contaminants to water, carbon dioxide, and other substances. The ultraviolet light also kills the biospecies in the airflow that are irradiated.

Disadvantageously, typical air treatment module filters have a finite contaminant capacity. Once the contaminant capacity is reached, the filter does not physically separate additional contaminants from the air stream. Contaminants in the air stream may then flow through the filter and become oxidized by the photocatalyst. This is particularly troublesome when the photocatalyst oxidizes silicon-containing VOCs or SVOCs to form a silicon-based glass on the photocatalyst surface. The silicon-based glass may insulate the titanium dioxide from the passing air stream, thereby passivating the titanium dioxide. In severe instances, much of the catalytic activity of the photocatalyst may be lost within two weeks of reaching the contaminant capacity of the filter. To prevent photocatalyst passivation, the filter may be replaced before reaching the contaminant capacity or additional filters may be utilized to physically separate a greater amount of the contaminants, however, the maintenance required to replace a filter in short time intervals or continually monitor a filter may be expensive and inconvenient.

Accordingly, an air treatment module that more effectively protects the photocatalyst from passivating contaminants is needed.

SUMMARY OF THE INVENTION

In general terms, this invention is a system and method for protecting a photocatalyst in an air treatment system from passivation caused by oxidation of certain contaminants.

In one example, the air treatment module includes a filter and heating element, a plasma device, and a photocatalyst and UV light that cooperate to purify an air stream flowing

through the air treatment module. The air treatment module operates in two different modes. In the first mode, the air treatment module primarily draws air from and returns air to a space, and the heating element and plasma device are shut off. In the second mode, the air treatment module regenerates the filter using the heating element to heat the filter and release adsorbed contaminants. The plasma device is selectively turned on and chemically transforms the released contaminants into solid contaminant products, which are deposited on a biased electrode of the plasma device. The UV light is turned off to ensure that the photocatalyst is inoperable during the release and transformation of the contaminants. Once deposited, the essentially immobile and inert solid contaminant products are unlikely to damage the photocatalyst.

An example method includes retaining the contaminants in the gas flow path when the photocatalyst is in an on condition, releasing the contaminants into the gas flow path when the photocatalyst is in an off condition, and chemically transforming the contaminants into different chemically transformed contaminants.

The various features and advantages of this invention will become apparent to those skilled in the art from the following detailed description of the currently preferred embodiment. The drawings that accompany the detailed description can be briefly described as follows.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a HVAC system including an air treatment module.

FIG. **2** is a perspective view of an example air treatment module.

FIG. **3** is a schematic view of an example filter, plasma device, and photocatalyst.

FIG. **4** is a schematic view another example of the filter of FIG. **3**.

FIG. **5** is a schematic view an example air treatment module that includes an ozone-destroying material.

FIG. **6** is a schematic view of another air treatment module configuration that includes a second plasma device.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** illustrates a residential, commercial, vehicular, or other structure **10** including an interior space **12**, such as a room, office or vehicle cabin. An HVAC system **14** heats or cools the interior space **12**. Air in the interior space **12** is drawn into the HVAC system **14** through an inlet path **16**. The HVAC system **14** changes the temperature and purifies the air drawn using an air treatment module **18**. The purified, temperature-changed air is then returned to the interior space **12** through an outlet path **20**.

FIG. **2** illustrates a perspective view of an example air treatment module **18**. The air treatment module **18** includes a compressor **30** for drawing and returning the air. Air drawn from the interior space **12** flows in an air stream **32** into a filter cabinet **34**, which forms an air flow path through the air treatment module **18**. The filter cabinet **34** encloses a filter **36**, plasma device **38**, and photocatalyst **40** that cooperate to purify the air stream **32**. The air stream **32** continues through the filter cabinet to the coils **42**. The coils **42** heat or cool the air stream **32**, depending on the desired interior space **12** temperature. After being heated or cooled, the compressor **30** returns the air stream **32** to the interior space **12** through the outlet path **20**. It is to be understood that the air treatment module **18** shown is only one example and that the invention is not limited to such a configuration.

FIG. **3** illustrates a schematic view of an example filter **36**, plasma device **38**, and photocatalyst **40**. The filter **36** receives the air stream **32** and adsorbs contaminants from the air stream **32**. The filter **36** includes a known activated carbon filter media held between layers of a fibrous mesh **44**. In one example, the known activated carbon is modified, impregnated, or pore-controlled. As is known, a modifier such as potassium permanganate or other modifier may be impregnated in the activated carbon to modify the adsorptive properties of the activated carbon. The pore volume of the activated carbon may also be controlled within a desired range to modify the adsorptive properties. These features may provide the advantage of designing the filter **36** to preferentially adsorb certain contaminants, such as formaldehyde, acetaldehyde, toluene, propanol, butene, silicon-containing VOCs, or other VOCs.

In another example, the filter **36** may additionally utilize a zeolite and/or other type of filter media mixed with the activated carbon between the layers of fibrous mesh **44** to obtain preferential adsorption of certain contaminants. Alternatively, the activated carbon filter media may be integrated with the fibrous mesh **44** by coating the activated carbon onto fibers that make the fibrous mesh **44**.

In another example, the activated carbon filter media is provided in a first layer **46** and the zeolite media and/or other filter media may be provided in an adjacent second layer **48**, as illustrated in FIG. **4**.

A heating element **50**, which is discussed in more detail below, surrounds the filter **36** and is selectively operable between and on and an off condition.

In one example, the plasma device **40** is located generally downstream from the filter **36** and is selectively operable between an on and an off condition. Preferably the plasma device **38** is a corona discharge device that generates a plasma glow discharge. Even more preferably, the plasma device **38** includes a biased electrode **54**, such as a wire cathode.

The photocatalyst **40** is, in one example, located downstream from the plasma device **38**. Preferably the photocatalyst **40** is a titanium dioxide coated monolith, such as a honeycomb, that operates as a photocatalyst to destroy contaminants when illuminated with an ultraviolet (UV) light **56**. It is to be understood that photocatalyst materials other than titanium dioxide and configurations other than shown (for example, integrating the photocatalyst **40** with the filter **36** in a single unitary fibrous or honeycomb structure) may be utilized.

The UV light **56** is selectively operable between an on condition in which the photocatalyst **40** operates to destroy contaminants, and an off condition in which the photocatalyst **40** is inoperable. In one example, the UV light **56** illuminates the photocatalyst **40** with UV-C range wavelengths, however, other UV wavelength ranges may be utilized depending on the type of photocatalyst and/or air purifying needs of the air treatment module **18**.

Operationally, the exemplary air treatment module **18** functions in two different modes. In the first mode, the air treatment module **18** functions primarily to move air from and return air to the interior space **12** and to purify the air. In the first mode, the heating element **50** is selectively turned off, the plasma device **38** is selectively turned off, and the UV light **56** is selectively turned on. Thus, the filter **36** captures, traps, and adsorbs certain contaminants from the air stream **32**, such as VOCs and SVOCs, and the photocatalyst **40** operates to destroy other contaminants that pass through the filter **36**. The heating element **50** and plasma device **38** do not function in the first mode, however, in other examples it may be advantageous to simultaneously operate the heating element **50** and plasma device **38** with the functions of filtering and moving the air.

In the second mode, the air treatment module **18** functions primarily to regenerate the filter **36**. That is, the activated carbon or other adsorbent filter media is conditioned to desorb the previously adsorbed contaminants. The air stream **32** is shut off such that there is essentially zero air flow in the filter cabinet **34**. The heating element **50** is selectively turned on and heats the filter **36** to approximately 100° C., although other heating temperatures or heating profiles may also be utilized. The filter **36** desorbs and releases the contaminants previously adsorbed. The plasma device **38** is selectively turned on and generates a plasma, and the UV light **56** is preferably turned off to prevent the photocatalyst **40** from oxidizing the released contaminants.

The filter cabinet **34** holds the released contaminants and acts essentially as a reactor vessel for the plasma device **38**. The released contaminants, such as VOCs, SVOCs, or other contaminants that the filter **36** was designed to adsorb/release, contact the plasma generated by the plasma device **38**. The plasma chemically transforms the contaminants into solid contaminant products and deposits the solid contaminant products onto a receiving portion, the biased electrode **54**. Once deposited, the essentially immobile and inert solid contaminant products are unlikely to damage the photocatalyst **40**. In one example, the plasma deposits the solid contaminant products onto a wire cathode. After a predetermined number of deposit cycles, the wire cathode is removed from the plasma device **38** and discarded or cleaned.

While in the second mode, the heating element **50** and plasma device **38** operate for a selected predetermined amount of time. Preferably, the time is adequate to i) release most of the contaminants from the filter **36**, and thus regenerate the filter **36** and ii) transform the contaminants to solid contaminant products. The time required will vary with temperature, size and type of filter media, size of the filter cabinet **34**, and the size and type of plasma device **38** used.

Preferably, the UV light **56** remains off when switching from the second mode to the first mode to protect the photocatalyst **40** from any remaining contaminants that have not been transformed to solid contaminant products. The air stream **32** flows through the filter cabinet **34** for a selected predetermined amount of time to purge the remaining released contaminants before turning on the UV light **56** to operate the photocatalyst **40**.

In another example, the contaminant products include organic silicon compounds, such as silicon-containing VOCs and silicon-containing SVOCs. The filter **36** releases the organic silicon compounds upon heating and the plasma generated by the plasma device **38** chemically transforms the organic silicon compounds into silicon dioxide or other silicon-based glass. The plasma deposits the silicon dioxide or other silicon-based glass on the biased electrode **54**.

In another example, the filter **36** includes a single pleated layer with a pleating factor of about 8 and about 100 g of activated carbon filter media. The filter **36** adsorbs approximately 90% of the organic silicon compounds in the incoming air stream **32** and takes approximately twelve hours to reach full capacity in first mode operation. Near the twelve hour time, the air treatment module **18** utilizes, for example, a controller to automatically switch into the second mode and regenerate the filter **36**. Alternatively or in addition to the controller, an operator may control the switching between modes.

In another example shown in FIG. **5**, an ozone-destroying material **58**, such as a known metal oxide catalyst, is included between the plasma device **38** and the photocatalyst **40**. The ozone-destroying material **58** may be disposed on a honeycomb structure **60**, for example, and receives ozone from the plasma device **38** before switching the UV light **56** on. The ozone-destroying material **58** adsorbs ozone onto the surface and decomposes the ozone. This feature may provide the advantage of exposing the photocatalyst **40** to less ozone, which may contribute to photocatalyst **40** passivation. It is to be understood that the ozone-destroying material **58** may alternatively be positioned in other locations in the filter cabinet **34** than shown.

FIG. **6** illustrates a schematic view of another air treatment module **18** configuration including a second plasma device **138** surrounding the filter **36**. The second plasma device **138** includes a biased electrode **154** and operates similarly to and in conjunction with the plasma device **38** to chemically transform released contaminants into solid contaminant products. Utilizing the second plasma device **138** may provide the benefit of shorter times to fully chemically transform the contaminants released from the filter **36** or greater efficiency in transforming the released contaminants. Likewise, a multitude of additional plasma devices may be used.

Although a preferred embodiment of this invention has been disclosed, a worker of ordinary skill in this art would recognize that certain modifications would come within the scope of this invention. For that reason, the following claims should be studied to determine the true scope and content of this invention.

We claim:

1. A gas treatment system for treating a gas stream containing contaminants comprising:

a filter disposed in a gas flow path;

a heating element including first and second spaced-apart sides adapted to heat said filter, with the filter arranged between said first and second spaced-apart sides and adjacent to said first and second spaced-apart sides;

a photocatalyst in fluid communication with said filter; and

a plasma device in fluid communication with said photocatalyst, said plasma device positioned to treat contaminants in the gas flow path.

2. The system as recited in claim **1**, wherein said plasma device is positioned upstream from said photocatalyst.

3. The system as recited in claim **1**, wherein said plasma device is positioned downstream from said filter.

4. The system as recited in claim **1**, wherein said filter is adapted to retain at least a portion of the contaminants in the gas stream when said photocatalyst is in an active condition with respect to receiving light for destroying the contaminants and later selectively releases the contaminants when said photocatalyst is in an inactive condition with respect to receiving any light, and said plasma device is positioned adjacent to said filter to chemically transform the contaminants that said filter releases.

5. The system as recited in claim **4**, including an ozone-destroying material in fluid communication with said plasma device, said ozone-destroying material adapted to receive ozone at least from said plasma device.

6. The system as recited in claim **1**, wherein said filter at least includes activated carbon adapted to adsorb contaminants from the gas stream to retain the contaminants when the gas stream contacts the activated carbon.

7. The system as recited in claim **1**, wherein said plasma device is one of a plurality of plasma devices in fluid communication with said photocatalyst.

8. The system as recited in claim **1**, wherein said filter includes a first layer and a second layer adjacent to the first layer, said first layer comprising activated carbon and said second layer comprising zeolite.

9. The system as recited in claim **1**, wherein said filter is pleated.

10. The system as recited in claim **1**, wherein said filter and said first and second spaced-apart sides are pleated.

11. A gas treatment system for treating a gas stream containing contaminants comprising:

a photocatalyst arranged in a gas flow path to treat contaminants in a gas flow;

an ultraviolent (UV) light source adjacent to said photocatalyst for selectively activating said photocatalyst, said UV light source having an ON state for activating said photocatalyst and an OFF state for deactivating said catalyst;

a plasma device upstream from said photocatalyst for treating the contaminants, said plasma device configured to be in an ACTIVE condition for treating the contaminants when said UV light source is in the OFF state and in an INACTIVE condition for not treating the contaminants when said UV light source is in the ON state wherein the combination of the inactive condition and the ON state is a first mode in the combination of the active condition and the OFF state is a second mode;

a filter upstream of said plasma device for selectively retaining or releasing contaminants;

a heating element adjacent to said filter, said heating element configured to heat said filter when said UV light source is in the OFF state and the plasma device is in the ACTIVE condition to release contaminants from the filter such that said plasma device treats at least a portion of the released contaminants, and configured to not provide heat to said filter when said UV light source is the ON state and the plasma device is in the INACTIVE condition to retain contaminants from the gas flow; and

a controller in communication with said UV light source and said plasma device, said controller being configured to switch between said first mode and said second mode.

12. The system as recited in claim **11**, wherein said filter includes a first layer and a second layer adjacent to the first layer, said first layer comprising activated carbon and said second layer comprising zeolite.

13. The system as recited in claim **11**, wherein said filter is pleated.

14. The system as recited in claim **11**, wherein said filter and said first and second spaced-apart sides are pleated.

* * * * *